

# Suppression of Heating of Coronal Loops Rooted in Opposite Polarity Sunspot Umbrae

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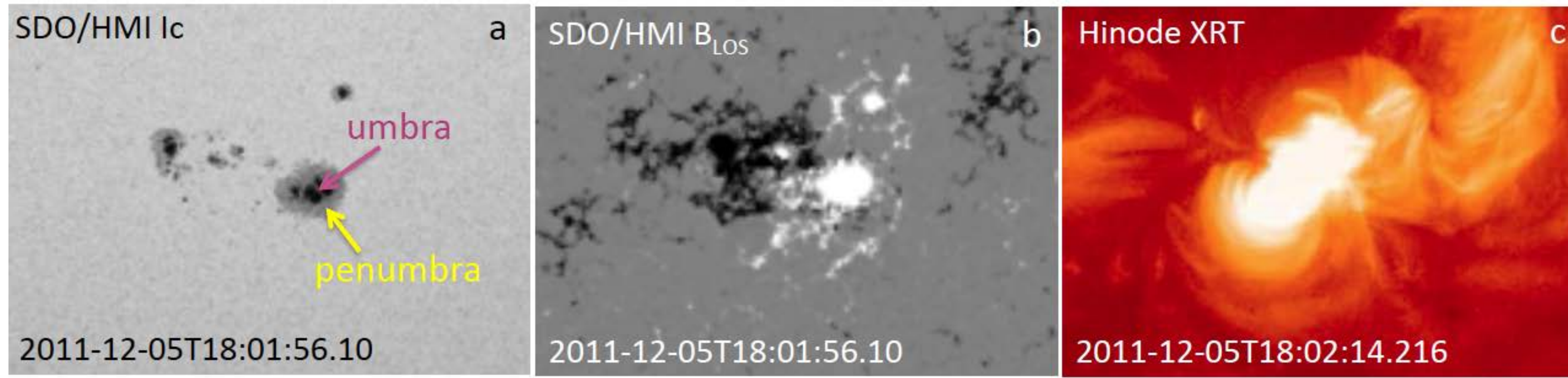
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## Abstract

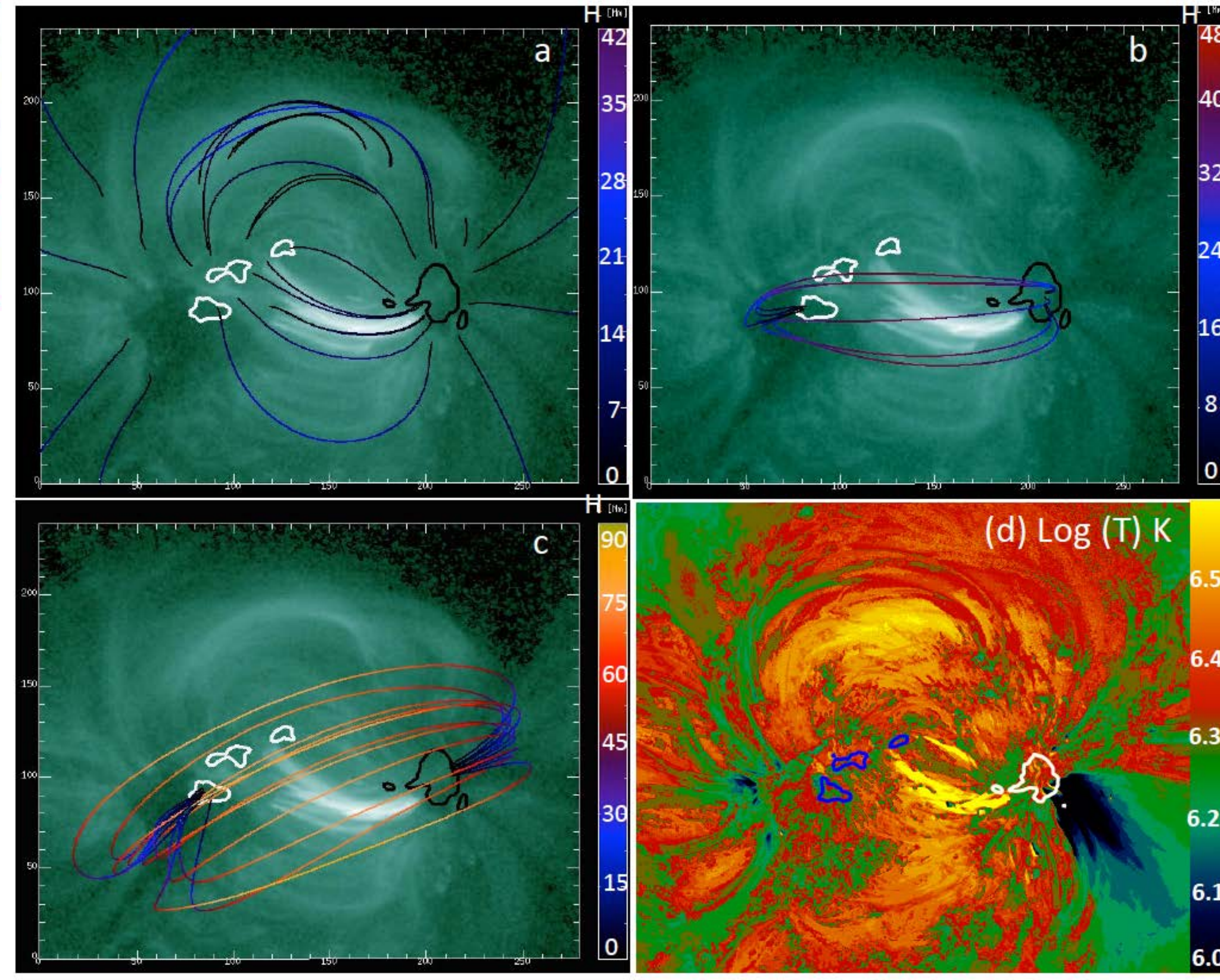
EUV observations of active region (AR) coronae reveal the presence of loops at different temperatures. To understand the mechanisms that result in hotter or cooler loops, we study a typical bipolar AR, near solar disk center, which has moderate overall magnetic twist and at least one fully developed sunspot of each polarity. From AIA 193 and 94 Å images we identify many clearly discernible coronal loops that connect plage or a sunspot of one polarity to an opposite-polarity plage region. The AIA 94 Å images show dim regions in the umbrae of the sunspots. To see which coronal loops are rooted in a dim umbral area, we performed a non-linear force-free field (NLFFF) modeling using photospheric vector magnetic field measurements obtained with the Helioseismic Magnetic Imager (HMI) onboard SDO. The NLFFF model, validated by comparison of calculated model field lines with observed loops in AIA 193 and 94 Å, specifies the photospheric roots of the model field lines. Some model coronal magnetic field lines arch from the dim umbral area of the positive-polarity sunspot to the dim umbral area of a negative-polarity sunspot. Because these coronal loops are not visible in any of the coronal EUV and X-ray images of the AR, we conclude they are the coolest loops in the AR. This result suggests that the loops connecting opposite polarity umbrae are the least heated because the field in umbrae is so strong that the convective braiding of the field is strongly suppressed.

## AR coronal loops are the brightest loops in the solar corona



**Fig. 1.** Example bipolar AR with sunspots. (a). HMI continuum intensity image. The umbra and penumbra of the largest sunspot are indicated by arrows. (b) HMI line-of-sight magnetogram of the AR at the same time. White/black areas have positive/negative magnetic polarity. (c) Hinode X-Ray Telescope image displaying hot coronal loops.

## Umbra-to-umbra loops are never visible in any of the AIA channels



**Fig. 2.** A frame from an AR's 24 hr 4-panel movie. From the AIA 94 and 193 Å panels of the movie we infer the following. Bright loops are episodic ( $\approx 1$  h). The brightest loops are rooted in umbra or in inner penumbra at one of their feet with the other foot rooted in unipolar plage or in penumbra or in mixed polarity plage. Plage-to-plage loops are never as bright as the above loops. Umbra-to-umbra loops are never visible. This AR was quiet on this day, i.e., it produced no flares greater than B-class.

**Fig. 3.** An AIA 94 Å image of the AR 12110 (on July 07, 2014 at 23:36 UT), with NLFF model field lines over-plotted on it; compared with AR's temperature map, displayed in the last panel. In panel (a) we show the example model field lines that match well with the observed loops in AIA 94 and 193 Å images. Panels (b) and (c) show a lower set and a (about twice) higher set of model field lines that are rooted in umbra at each of their feet. Field-line color gives field-line height in Mm. (d) Temperature map of the AR at the same time, produced by DEM analysis of six AIA channel images.

**Outlook:** From this result, we **hypothesize** that the convective freedom at the feet of a coronal loop, together with the strength of the field in the body of the loop, determines the strength of the heating. In particular, we expect the hottest coronal loops to have one foot in an umbra and the other foot in opposite-polarity penumbra or plage (coronal moss), the areas of strong field in which convection is not as strongly suppressed as in umbrae. Many transient, outstandingly bright, loops in the AIA 94 Å movie of the AR do have this expected rooting.

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